

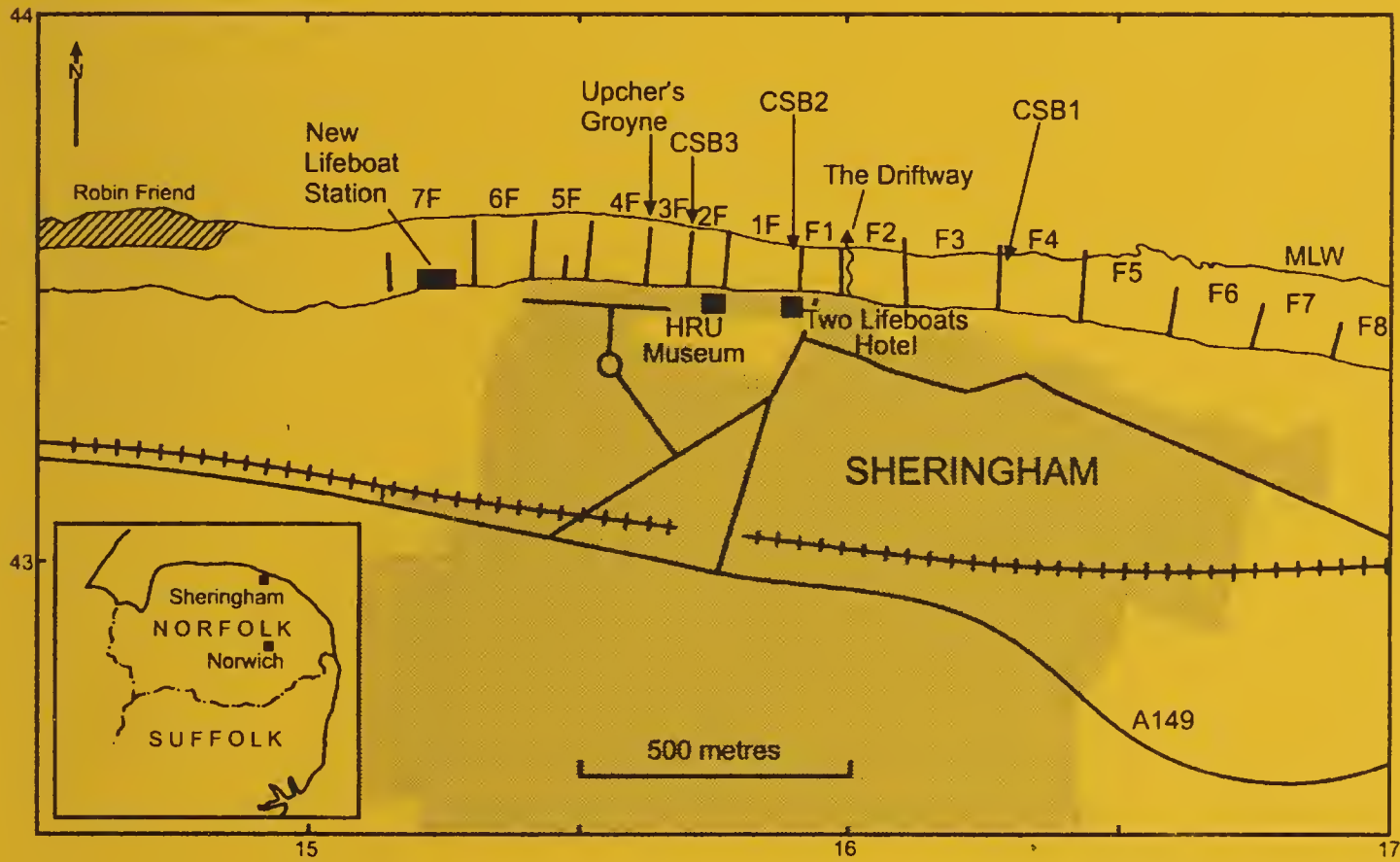
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# BULLETIN OF THE GEOLOGICAL SOCIETY OF NORFOLK

(FOR ARTICLES ON THE GEOLOGY OF EAST ANGLIA)

NO. 57

2007



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## PAUL WHITTLESEA MEMORIAL VOLUME

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CORRELATION OF NORFOLK CAMPANIAN  
CHALK STRATIGRAPHY



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# **BULLETIN OF THE GEOLOGICAL SOCIETY OF NORFOLK**

**No. 57 (2007) Published 2007**

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## **EDITORIAL**

In the editorial to Bulletin 56 I noted that Paul Whittlesea, with over 30 years of field research experience in Norfolk, could justly claim to be one of the few experts working actively on the local Chalk. I could not have foreseen that 8 months later Paul himself would be taken from us, leaving us bereft of a fine colleague and friend, but also taking from us our local Chalk expert. It is fitting then, that this Bulletin (57) is dedicated to Paul. Along with an obituary and publication list, this Bulletin contains the last papers that Paul was working on at the time of his death\*. The main paper is his attempted correlation of the coastal Beeston Chalk section, published in Bulletin 56, with the inland sections. The paper had been through peer review and was in the final stages of editorial smoothing at the time of his death. Paul knew that some of his interpretations and correlations in this paper might prove contentious, but he was firmly of the opinion that others should prove him wrong if they could; time will show whether they can. What I am quite sure of is that his painstaking mapping and logging of the coastal Beeston Chalk section will remain a lasting contribution to the geology of Norfolk.

\*Paul had other papers already started on his computer, but alas not complete enough for publication.

## INSTRUCTIONS TO AUTHORS

Contributors should submit manuscripts as word-processor hard copy. We accept typewritten copy and consider legible handwritten material for short articles only. When papers are accepted for publication we will request an electronic version. We can handle most word-processing formats although MS Word is preferred.

It is important that the style of the paper, in terms of overall format, capitalisation, punctuation etc. conforms as strictly as possible to that used in Vol. 53 of the Bulletin. Titles and first order headings should be capitalised, centred and in bold print. Second order headings should be centred, bold and lower case. Text should be 1½ line spaced. All measurements should be given in metric units.

References should be arranged alphabetically in the following style.

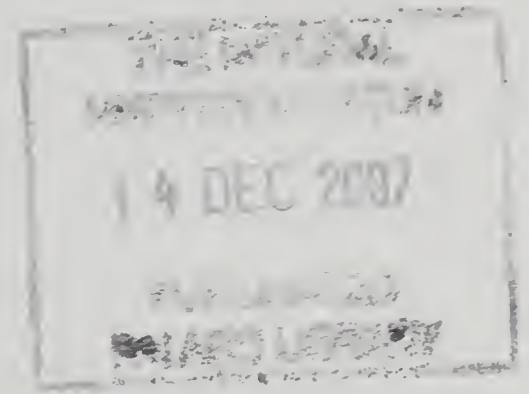
BALSON, P.S. & CAMERON, T.T.J. 1985. Quaternary mapping offshore East Anglia. *Modern Geology*, 9, 221-239.

STEERS, J.A. 1960. Physiography and evolution: the physiography and evolution of Scolt Head Island. In: Steers, J.D. (ed.) *Scolt Head Island* (2nd ed.), 12-66, Heffer, Cambridge.

BLACK, R.M. 1988. *The Elements of Palaeontology*. 2nd Ed., Cambridge University Press, Cambridge. 404pp.

Illustrations should be drawn with thin dense black ink lines. Thick lines, close stipple or patches of solid black or grey should be avoided as these can spread in printing. Original illustrations should, before reproduction, be not more than **175mm by 255mm**. Full use should be made of the first (horizontal) dimension which corresponds to the width of print on the page, but the second (vertical) dimension is an upper limit only. Half tone photographic plates are acceptable when their use is warranted by the subject matter, provided the originals exhibit good contrast.

The editors welcome original research papers, notes, comments, discussion, and review articles relevant to the geology of **East Anglia** as a whole, and do not restrict consideration to articles covering Norfolk alone. All papers are independently refereed by at least one reviewer.



## OBITUARY

### Paul S. Whittlesea (1957-2007)

Paul Whittlesea was, despite his non-professional status in geology, arguably the local expert on the Norfolk Chalk. With the recent deaths of both Jake Hancock and Brian Funnell, Paul along with Chris Woods and Norman Peake, knew most about the Norfolk Chalk; of these only Paul was actively researching in 2007.

Paul's interest in geology, mineralogy and palaeontology was sparked by his Auntie Maureen, who gave him an ammonite fossil when he was aged 9. He was hooked from that moment and was, at the age of 14, a founder member of the Norfolk Mineral and Lapidary Society. Two years later in 1973 he joined the Geological Society of Norfolk (GSN) and was soon an active and dedicated member. Paul gradually built up his knowledge and expertise over many years of field work and fossil collecting. Between November 1978 and October 1979 he also worked as curator's assistant at the Norwich Castle Museum. His job was to catalogue minerals, however, he spent many lunchtimes working on chalk fossils with the Museum's newly acquired air abrasive tool! In 1983, strongly encouraged by Prof. Brian Funnell at the University of East Anglia in Norwich, he published his first papers in the GSN Bulletin (see publication list). That year he also took on his first committee role as Field Meeting Secretary. In 1990 he stepped up to be General Secretary, a post he held until 1995, and in 1993 took over editing the Newsletter. Following on from Philip Cambridge he ensured the success of the Newsletter, often contributing short articles; his editorials were distinctive, sometimes provocative, but always interesting; his editorial stint continued until 2000. He was making regular contributions to the Newsletter up to his death, his final posthumous contribution in Newsletter No. 69 (April 2007). In 1996-1999 he again became Field Meeting Secretary, and in 1996 he was making a start on setting up a website for the society. Indeed during the late 1990s his considerable energy helped keep the society going during a lean period. He retired from the committee in 2000, but agreed to become the Honorary President for that year. Retirement did not last long: in 2001-2002 he stepped in as acting General Secretary

when Vanessa Banks left Norfolk to do a Ph.D; in 2002 he acted as the first GSN Webmaster, became Acting Treasurer in 2003 and then did a further full year as Treasurer in 2004. Paul often held strong views and was not shy in airing them, either vocally or on paper. His attention to detail in the GSN constitution was legendary! It is safe to say that no other single person, in the history of the GSN has done more for the society. In March 2006 he was made an Honorary Life Member of the society he loved: fitting recognition for his stalwart service.

Paul was dedicated to Chalk bryozoa, a subject he became internationally known for (see below). He was foremost a palaeontologist but with considerable knowledge and interest in Chalk stratigraphy, palaeoenvironments and glaciectonics, publishing scientific papers on all these aspects (see publication list). Conservation of Chalk sites was a high priority and he acted as a warden for English Nature, looking after two geological SSSI's in Norwich. In late 1985 he initiated GSN 'Project Sidestrand' aimed at mapping the UK's only Maastrichtian Chalk outcrops at Sidestrand, provoked by plans of North Norfolk District Council to extend sea defences close to the outcrops, thereby stabilising the sand cover year round. By October 1986 he and others had completed 13 visits to the site and had mapped 60-65% of the extant intertidal exposures.

In 1992 Paul followed up his Sidestrand success with the ambitious proposal to map the Beeston Chalk between Sheringham and West Runton: a hit and miss project given that most of the exposure was intermittently covered in sand, except in the winter months. He started that same year, 1992, setting out to visit the site every fortnight on a Saturday (often by bicycle from Norwich, latterly by train). There is no record of anyone joining him: our suspicion is that he did this work more or less on his own. Nonetheless by 2005 he had put together all the information to form a stratigraphic section: no other professional or amateur geologist in the history of British Geology had managed to do this before. The results of this monumental effort were published in Bulletin 56 (Whittlesea 2006; see publication list) and form the basis of the correlation paper in this issue (No. 57) of the Bulletin (Whittlesea 2007a); he was still making final revisions at the time of his death.

Paul had an 'up-and-down' relationship with Norwich Castle Museum, no doubt starting with his temporary employment in 1978 to 1979 (see above). In 1985 he donated his valuable (ongoing) research collection of Norfolk Chalk fossils to the Museum. This collection contained almost a thousand very good, well-identified and well-provenanced fossils, mostly bivalves, sponges, echinoderms, brachiopods and bryozoa. However, during the later 1980s and through the 1990s he found it increasingly difficult to conceal his ire about – in his perception at least – the state of storage, access and curation of his and other geological collections. In 1997 things reached a low when he expressed deep concern (GSN Newsletter No. 40) that the 'Tate in East Anglia' plans were being pursued with scant attention to the display, access and curation of the local collections, particularly the geological ones. Feeling strongly that management should be accountable he sought and had a meeting with the Director of Norfolk Museum's Service and clearly made his opinions known!

Happily by the mid 2000s Paul was reconciled with the Castle Museum. Just before he died, Paul worked there on a short-term contract for four months to catalogue prioritised areas of the large collection of chalk fossils donated the previous year by the well-known local Chalk expert Norman Peake. It can safely be said that no-one else would have had Paul's ability to check the identifications, understand Norman's abbreviations for locations, add missing stratigraphical details and note the epifauna on the specimens. As a result, during his short contract Paul added over four thousand very detailed records to the Castle Museum's online geology collections database. Moreover, Paul's family have now generously donated the rest of his personal collection to the Museum, totalling several thousand chalk fossils, a significant proportion of which are bryozoa.

Paul was not just another local amateur geologist. He had established international collaborations with Chalk workers in many parts of Europe and as far afield as New Zealand. He was well known among bryozoologists, following in the footsteps of R.M. Brydone, A.G. Davis, Leslie Pitt and others in continuing a tradition for amateur geologists in Britain to make significant contributions to bryozoological science. He was studying the systematics and biostratigraphy of cribrimorph

cheilostome bryozoans at the time of his death and attended at least two of the International Conferences of the International Bryozoology Association (IBA). They had expected to welcome him to their most recent conference in North Carolina in July 2007. Sadly, he was one of the names of newly deceased members of the IBA read out during the conference.

**Julian Andrews (UEA, Norwich), Nigel Larkin (Castle Museum, Norwich), Paul Taylor (British Museum Natural History, London)** **31 August 2007**

#### **PUBLICATION LIST - PAUL S. WHITTLESEA**

- WHITTLESEA, P. S. 2007a. Correlating the Inland and Coastal Beeston Chalk of Norfolk. *Bulletin of the Geological Society of Norfolk*, **57**, 9-32.
- WHITTLESEA, P. S. 2007b. Further observations on the Beeston Chalk in the vicinity of Water Lane, West Runton. *Bulletin of the Geological Society of Norfolk*, **57**, 33-35.
- WHITTLESEA, P. S. 2006a. The intertidal outcrop of the Upper Campanian Beeston Chalk between Sheringham and West Runton, Norfolk. *Bulletin of the Geological Society of Norfolk*, **56**, 3-32.
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- WHITTLESEA, P. S. 1985. Notes on Chalk fossils: 1. Notes on a temporary section at Bramerton, near Norwich; 2. Occurrence of the brachiopod *Kingenella kongieli* Popiel-Barczyk in the Norwich Chalk; 3. Preliminary account of a Bryozoan - "Algal" association from the Upper Campanian and Maastrichtian of Norfolk. *Bulletin of the Geological Society of Norfolk*, **35**, 39-46.

- WHITTLESEA, P. S. 1983a. Observations on the stratigraphical range and morphology of the Cretaceous Cribrimorph bryozoan: *Ubaghsia crassa* (Lang). *Bulletin of the Geological Society of Norfolk*, **33**, 27-31.
- WHITTLESEA, P. S. 1983b. The occurrence of the brachiopod genus *Rugia* Steinich in the Norwich Chalk. *Bulletin of the Geological Society of Norfolk*, **33**, 32-33.

*[Compiled 23 August 2007 by J.E. Andrews]*

# CORRELATING THE INLAND AND COASTAL BEESTON CHALK OF NORFOLK

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## ABSTRACT

*A correlation of the Beeston Chalk between the coastal section at Sheringham-West Runton and the inland sections, principally that at Caistor St. Edmund, is proposed. Clarification of the likely position of the main Catton Sponge Bed (CSB 3) on the foreshore at Sheringham in front of the easterly located Lifeboat Station, allows more confident identification of the base of the Beeston Chalk on the coast and reduces the length of the intertidal outcrop from 4.4 km (Whittlesea, 2006) to ~3.2 km. Using the height of a composite vertical section of the inland Beeston Chalk exposures, and its correlation with the coast, a coastal dip of 6.4 m/km is calculated. The calculated thickness of the Beeston Chalk on the coast is consequently revised down from ~26 m (Whittlesea, 2006) to ~20 - 21 m, which verifies earlier estimates. Review of the inland Beeston Chalk stratigraphy includes new proposals for correlation between the sections at Caistor St. Edmund, Stoke Holy Cross and Frettenham.*

## INTRODUCTION

This paper, drawing on published research and new data, discusses the possible correlation of inland and coastal exposures of the Beeston Chalk, part of the upper Upper Campanian Norwich Chalk succession in Norfolk (Fig. 1). The study area on the north Norfolk coast includes the full sub-crop and outcrop of the Beeston Chalk; exposures were studied on the modern inter-tidal platform. The structure of the Norfolk Chalk imposes strict constraints on any correlations proposed between the coast and inland. The strike of the Chalk in Norfolk is approximately N-S and the formational dip is easterly, but low, about 6.6 m/km in central Norfolk (Boswell, 1920) reducing eastwards. The surface dip is lower still, about 1.5 m/km, thereby preserving younger zones eastward.

The dip in south Norfolk is about half that in central Norfolk, resulting in broader zonal outcrops there.

Using these structural data it is possible to determine a maximum value for the thickness of the Beeston Chalk. The total thickness of any correlated sections must either be close to the maximum value, or clear testable arguments must be advanced to defend departure from it. The low dip also means that a bed seen in vertical section has a broad outcrop on the intertidal platform; e.g. a bed 0.66 m thick would crop out over a 100 m section of intertidal platform using the formational dip of Boswell (above). For simplicity, Whittlesea (2006) used a working figure of 5 m/km to calculate the thickness of the Beeston Chalk on the intertidal platform of the north Norfolk coast. This was primarily because no correlation had been suggested between the horizontal beach outcrop and any known vertical section elsewhere. It would have been both premature and impossible to justify a figure prior to this, although the Beeston Chalk outcrop and subcrop here is only slightly east of the centre of the county, such that the actual dip might reasonably have been expected to be close to that given by Boswell.

## **METHODS**

Correlation between the various Beeston Chalk localities discussed in this paper (Fig. 2) is based primarily on stratigraphic marker horizons (hardgrounds, flint bands etc.) and supported by lithofacies information where appropriate.

Descriptions of vertical sections at inland sites have been published over many years, the most recent overview being that of Wood (1988). Measured sections and correlations between Catton Grove (NGR TG 2289 1094), Halfway House (NGR TG 2330 0268), Stoke Holy Cross (NGR TG 2356 0140) and Caistor St. Edmund (NGR TG 2390 0466) by Wood (1988 figs. 7 & 8) are reproduced here in Figures 4 & 6, emended to reflect their current condition and updated with recent observations. All flint marker bands from these sections are labelled alphabetically from the top down starting at 'A'; hardgrounds are given numbers from the top down, starting at '1'. (This is because working quarries are continually being deepened, exposing additional features).

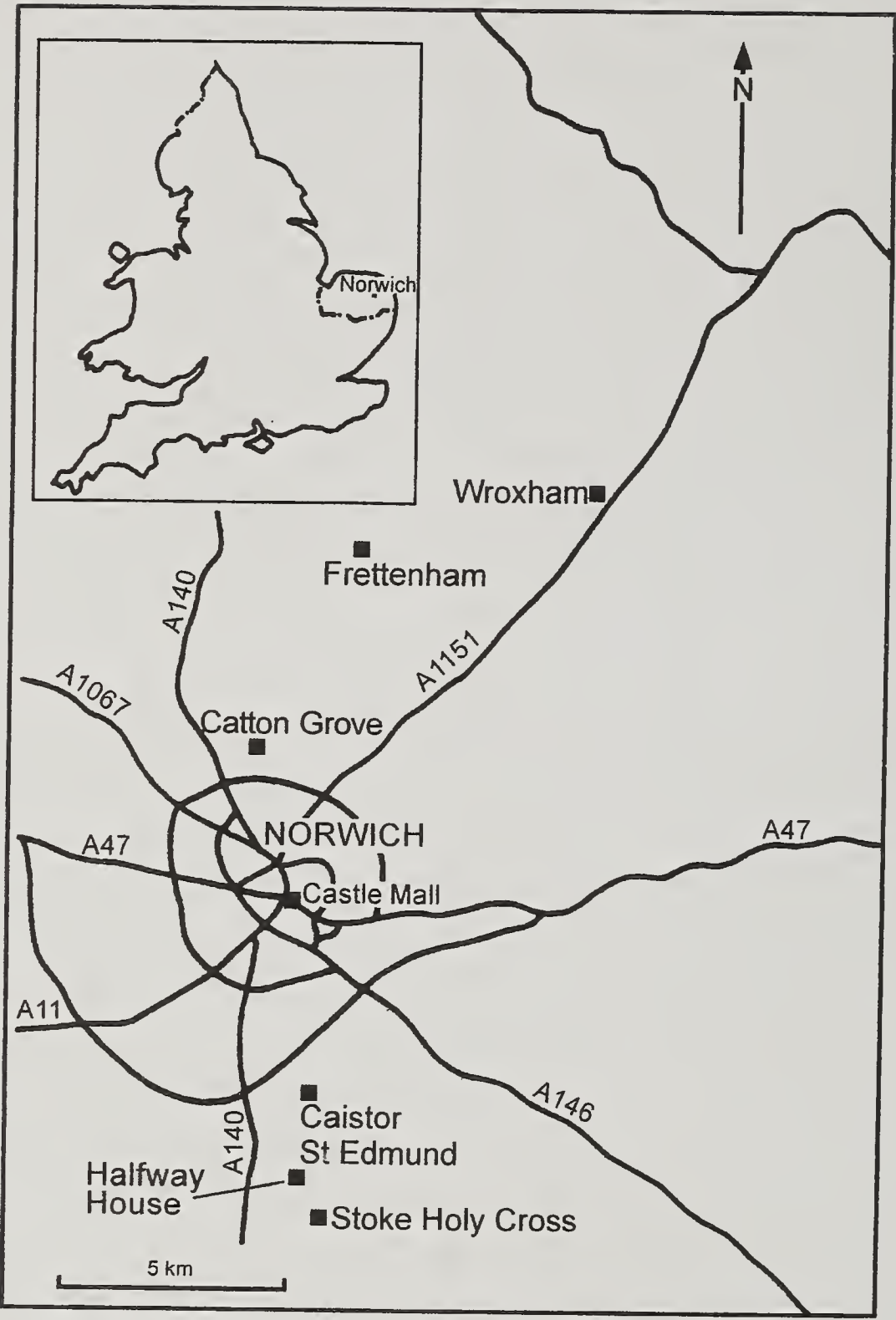
The intertidal coastal exposures were not logged in this way: instead, lithological or palaeontological marker horizons (flint bands, sponge beds etc), seen in this eastward younging sequence, were logged by determining the precise location of the base of the marker horizon on the foreshore. In practice this meant locating the westernmost edge of the marker at low tide (Whittlesea 2006). The coastal marker horizons are labelled from base up, using the nomenclature of Whittlesea (2006). The markers are spatially located

Peake & Hancock (1961) "faunal belts"	Wood (1988)	Johansen & Surlyk (1990) Lithostratigraphy	Johansson & Surlyk (1990) brachiopod biostratigraphy	Christensen (1995) belemnite biostratigraphy	Christensen (1995) relationship to Wood (1988)	
Paramoudra Chalk	Paramoudra 2 Chalk	Paramoudra Chalk Member	<i>longicollis</i> - <i>jasmundi</i>	<i>B. minor II</i> & <i>ex. gr. langei-najdini</i>	Paramoudra 2 Chalk	
	Paramoudra 1 Chalk			<i>Belemnitella minor II</i>	Paramoudra 1 Chalk	
Beeston Chalk	Beeston Chalk	Beeston Chalk Member	<i>tenuicostata</i> - <i>longicollis</i>	<i>B. minor I, pauli</i> & <i>najdini</i>	Beeston 3 Chalk	
				<i>B. minor I</i> & <i>langei</i>	Beeston 2 Chalk	
<i>Belemnitella minor I</i>	Beeston 1 Chalk					
Catton Sponge Beds (2)*	Catton Sponge Beds (3)*	Catton Sponge Beds				Catton Sponge Beds (3)*
Weybourne Chalk	Weybourne 3 Chalk	Weybourne Chalk Member		<i>Belemnitella woodi</i>	Weybourne Chalk	
	Weybourne 2 Chalk					
	Weybourne 1 Chalk					
Eaton Chalk	Pre-Weybourne 5 Chalk	Eaton Chalk Member		<i>Belemnitella mucronata</i>	?	Pre-Weybourne 5 Chalk
	Pre-Weybourne 4 Chalk					Pre-Weybourne 4 Chalk
	Pre-Weybourne 3 Chalk					Pre-Weybourne 3 Chalk
	Pre-Weybourne 2 Chalk					Pre-Weybourne 3 Chalk
Basal <i>mucronata</i>	Pre-Weybourne 1 Chalk	?		?	?	?
5 units	11 units	5 members	2 'zones'	7 zones or zonal assemblages		

Fig. 1. Stratigraphy of the Norwich Chalk (Campanian).

\*The Catton Sponge Beds are a series of major hardgrounds that straddle the junction between the Weybourne and Beeston Chalks. They are not a biostratigraphic unit in their own right although Johansen & Surlyk (1990) accord them member rank in their lithostratigraphy. Peake & Hancock (1961) initially recognised two sponge beds at the stratotype. Wood (1988) subsequently identified a third lower in the sequence there, and Peake & Hancock (2000) reported four at Castle Mall, Norwich, the newest being at the top of the sequence. The terminal erosion surface of the second hardground from the base marks the top of the Weybourne Chalk.

Data in this table is from Peake & Hancock (1961, 1970), Wood (1988), Johansen & Surlyk (1990), Christensen (1995) and Whittlesea (2006). Precise correlation between units cannot be assumed as different criteria are used for litho- and biostratigraphy.



**Fig. 2.** Locality map showing inland localities of Beeston Chalk exposures mentioned in the text.

relative to reference frames provided by beach groynes (Whittlesea 2006). Frame “F1” is at the point (NGR TG 159 435) where Sheringham High Street meets the promenade in front of the Two Lifeboats Hotel. Frames east of here run to F14. Frames running west from F1 were identified as “1F” ... “6F”, (i.e. 1F and F1 are back-to-back). A revised map of these reference frames is provided here as Figure 3.

### **BEESTON CHALK STRATIGRAPHY**

The base and lower part of the Beeston Chalk is characterised by the Catton Sponge Beds (CSBs). These are a series of four hardgrounds, the terminal erosion surface of the third of which marks the base and junction with the underlying Weybourne Chalk (Wood, 1988). The top of the Beeston Chalk is taken at the terminal erosion surface of the major omission surface (MOS) that crops out on the foreshore approximately 150 - 200 m east of Water Lane, West Runton (F14, Fig. 3). This site is also the stratotype for the base of the succeeding Paramoudra Chalk. The stratum immediately above the Water Lane MOS is known as the “Bone Bed” because it has yielded a significant number of marine reptile bones, although extremely rare (five specimens in the last twenty-five years). Recent research by the author has shown there are actually at least two adjacent ‘Bone Beds’ at the coast. The lower is easily distinguishable because the chalk is yellow and the bones are brown in colour; in the upper the chalk is white and the bones are darker and associated with much pyrite. In Norwich the “Bone Bed” was exposed in a former chalk pit behind the gasholder, near Gas Hill (NGR TG 241 091) and also at Lollards Pit, now Lollards Road (NGR TG 239 085), both near Riverside Road.

#### **The Catton Sponge Beds (CSBs)**

Correlation of inland sections of the Beeston Chalk with each other and with the coastal exposures is based on identification of the CSB hardgrounds (Table 1). Inland, these four hardgrounds are spaced at ~1 m intervals. Hardgrounds 2 – 4 crop out at the stratotype, Catton Grove SSSI (NGR TG 2289 1094) although the youngest hardground is absent there. Hardground 2 is characterised by the presence of a highly distinctive form of *Echinocorys* (*E. 'bijouensis'* Peake M.S.) that also occurs on the foreshore in 1F (Fig. 3) in front of the Two Lifeboats Hotel, (formerly the ‘Bijou Hotel’) at Sheringham, (Peake & Hancock, 1961, 1970; Wood, 1988; Mortimore, *et al.*, 2001; Peake, pers. comm.). This observation provides an important link between the coast and inland exposures. If accepted, it forces any thickness calculation of the Beeston Chalk at inland localities above CSB 2, to reconcile the 2.8 km separating the Two Lifeboats Hotel and the base of

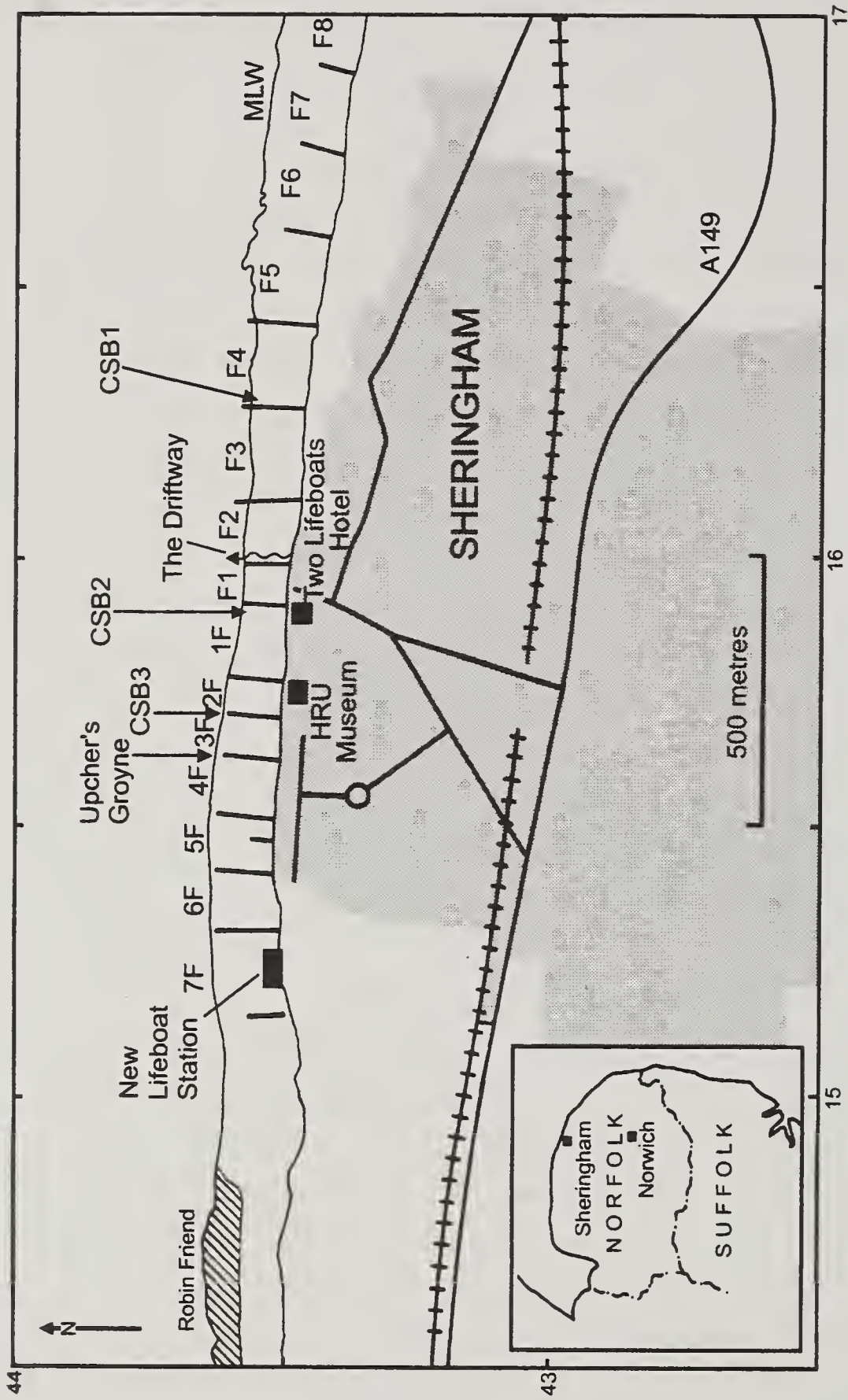
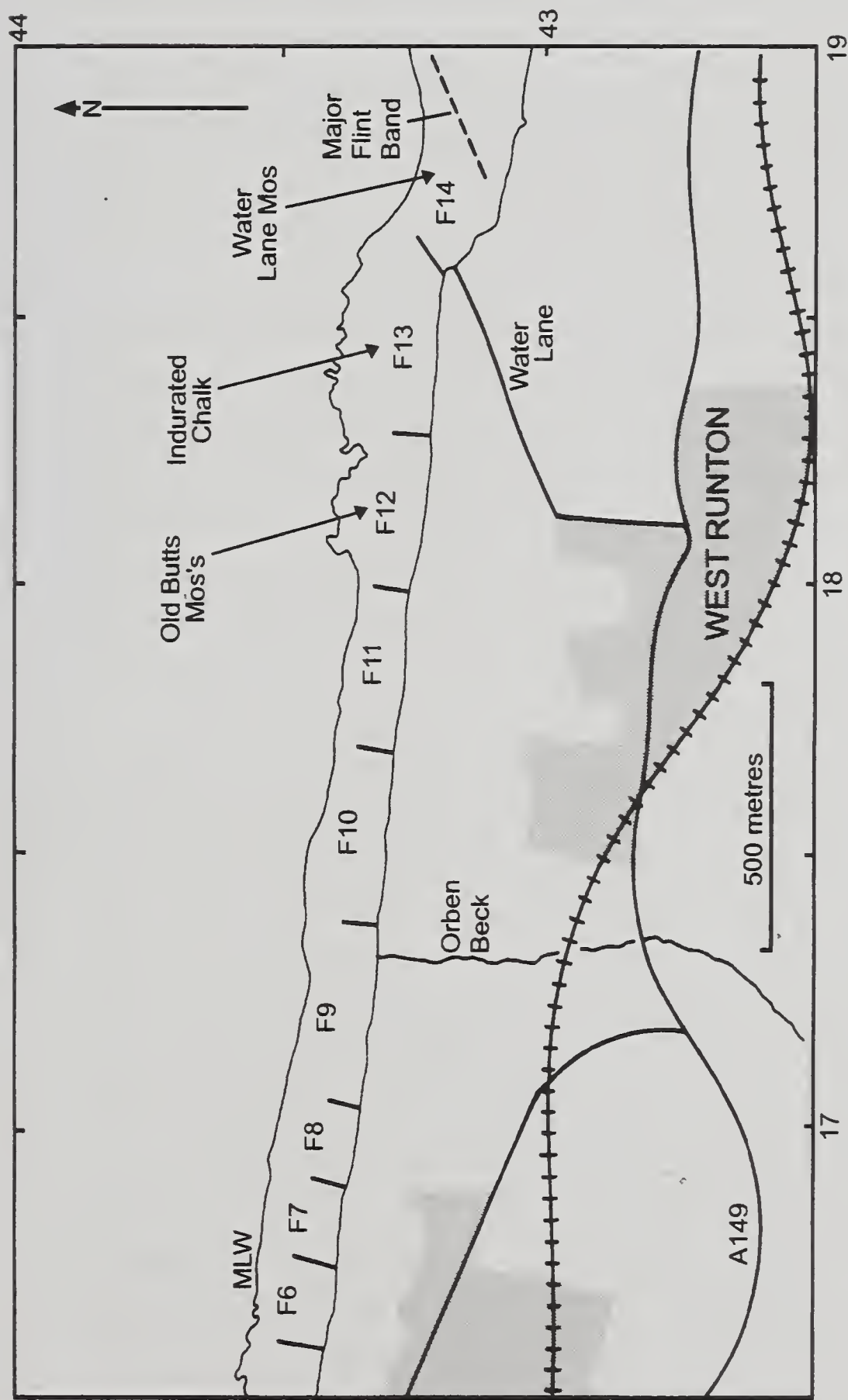


Fig. 3 [see legend p. 15]



**Fig. 3 [continued]** Sketch map of the foreshore between Sheringham and West Runton. Frame numbers (F1, F2 etc.) are shown between marker groynes. The easternmost edge of Frame 14 is approximately 100 m east of Water Lane, West Runton. National grid numbers are marked on the map boundary to aid orientation. Robin Friend is an outcrop of one of the higher hardgrounds in the Weybourne 3 Chalk (Fig. 1).

**Table 1.** Labels used for the Catton Sponge Beds (CSBs) by various authors.

Reference	Peake & Hancock (1961, 1970, 2000)			Wood (1988)	Mortimore <i>et al.</i> (2001)
CSB 1			1		
CSB 2	1	1	2	III	III
<b>CSB 3*</b>	<b>2</b>	<b>2</b>	<b>3</b>	<b>II</b>	<b>II</b>
CSB 4			4	I	I

\*The “main Catton Sponge Bed” recognised by all authors, and whose terminal erosion surface is taken as the top of the Weybourne Chalk, is shown in bold. In this paper the labels of Peake & Hancock (2000) are used.

the succeeding Paramoudra Chalk (the ‘Bone Bed’) at its stratotype at West Runton. Using dip values of 6.6 m/km (Boswell, 1920) and 5 m/km (Whittlesea 2006) across a horizontal distance of 2.8 km produces a figure for the thickness of this chalk of 18.48 m and 14.0 m respectively. The lower figure would not accommodate the known vertical thickness of that part of the Beeston Chalk exposed in Caistor St. Edmund chalk pit (16.31 m) and thus appears an underestimate. It is important to note however, that the *precise* locations of the westernmost boundaries of any of the Catton Sponge Beds on the coast are not known.

### Norfolk Coast Section: Historical Problems

It is important to document, and attempt to resolve here, the considerable confusion in the literature caused by errors in describing the outcrop of the Catton Sponge Beds and other hardgrounds on the north Norfolk coast (Peake & Hancock 1961; 1970; 2000; Wood 1988; Mortimore *et al.*, 2001). Peake & Hancock (1970, p. 339E) state that the “...very marked hardground in the deepest cuts within the [inland] Caistor [St. Edmund chalk] pit...may be the same as one near Upcher’s groyne at the eastern end of Sheringham promenade;” (this author’s emphasis). However, conversation with curatorial staff at the Henry Ramey Upcher lifeboat museum (NGR TG 158 436) and inspection of documentation prepared for north Norfolk District Council revealed that Upcher’s groyne is not at the current eastern or easternmost end of Sheringham promenade; it is between intertidal frames 4F and 3F (Fig. 3). Peake and Hancock clearly expected the hardground cropping out near Upcher’s groyne to be the youngest, or next youngest, of the CSBs. However, CSB 1 of Peake & Hancock (1970, 2000) could not

possibly have been near Upcher's groyne (between frames 4F and 3F), since that would place it between the outcrops of CSB 3, on which they say the "new" Lifeboat Station is built (frame 7F, Fig. 3), and of CSB 2 in front of the Two Lifeboats Hotel in frame 1F (Fig. 3). Moreover, the author, who has recently been cataloguing Mr. Peake's collection (donated to the Norfolk Museums and Archaeology Service), found a specimen of *Echinocorys* labelled "Beeston, [collected] *in situ*, 300 yards East of Upcher's groyne". This shows that Mr. Peake thought, mistakenly, that the easternmost groyne at Sheringham was Upcher's Groyne when Peake and Hancock (1970) referred to it. Since Beeston Hill is behind the foreshore between F6 and F7 that would place Upcher's Groyne, as they identified it (incorrectly), between F3 and F4.

Confusion also reigns over the terminology of the Lifeboat House and Station. The Henry Ramey Upcher lifeboat museum is located in the old Lifeboat House, formerly a privately funded Lifeboat Station within frame 2F (Fig. 3). This is in the middle of the west promenade, which extends from 7.0F to the easternmost point of 1F (Fig. 3). The "new" RNLI Lifeboat Station (housing the current lifeboat) shown on O.S. maps at NGR TG 153 436 is situated in 7.0F at the western end of the promenade (Fig. 3). Adding to the confusion the "Lifeboat House" and "Lifeboat Station" are shown as separate buildings in Frame 7F of Whittlesea (2006 fig. 2, p.8). There is only one building present here: the Lifeboat Station; this is corrected on Figure 3.

Mortimore *et al.* (2001, p. 358) state that: "...the old Lifeboat House (TG 153 436) is actually sited on the [main] Catton Sponge Bed". This is almost an exact transcription from Peake and Hancock (1970). However, the grid reference they provide is that of the new RNLI Lifeboat Station. Moreover, Mr. Wood (pers. comm., 2003) is not confident about the coastal location of the main Catton Sponge Bed and the succeeding hardground, recorded as cropping out in front of the Two Lifeboats Hotel. He is not convinced he ever saw a satisfactory exposure of these hardgrounds on the coast and took the location of these features from Peake and Hancock's earlier publications and from conversation with Mr. Peake.

Confusion has also resulted from both Peake & Hancock (1961, 1970), and Mortimore *et al.* (2001) providing imprecise locality details. For example, Peake & Hancock (1970, p. 339E) state that: "The lowest and most distinctive [hardground of the Catton Sponge Bed series] has the Lifeboat House built upon it". Later in the same paragraph they state that: "...the middle sponge bed at Sheringham, outcrops in front of the Two Lifeboats (formerly 'Bijou') Hotel...". The tidal range here is 2.5 – 5.0 m and there are probably at least some 1 – 2 metres between high tide mark and the top of the

low chalk cliff at Sheringham, the latter invariably hidden beneath beach shingle. Although this may seem a trivial point, in fact, well-separated (e.g.  $> \sim 1$  m) stratigraphic horizons in strata with very low dips crop out at locations quite remote from each other. If the actual thickness between any pair is calculated from their apparent separation, any difference in the height at which they crop out relative to a reference datum (e.g. a contour line, O.D. etc) must be ascertained. With such data a correction can be made, and their true vertical separation calculated. If this is not done any calculated value for the thickness will be exaggerated.

The chalk cliff, on which the current “new” Lifeboat Station (and much of the western promenade) is built, is thus probably 4 – 6 m above low water mark. It is not yet certain whether the “new” Lifeboat Station is built on the extreme westernmost edge of the main Catton Sponge Bed. However, given the provisional 5 m/km dip for the Chalk (Whittlesea, 2006) the top of the chalk cliff should crop out on the foreshore in either frame 3F or 2F (Fig. 3), which (ironically) puts it in front of the old Lifeboat House. Pending further observations, the extreme western edge of the main Catton Sponge Bed is placed at 2.0F (Fig. 3). Since frame 2F is some 200 m wide, this implies a separation of 1 m from the next youngest hardground, taken by Whittlesea (2006) to crop out in front of the Two Lifeboats Hotel at 1.0F. At the stratotype, Catton Grove SSSI (NGR TG 229 109), these Sponge Beds are separated by somewhere between 0.50 – 1.0 m (Peake & Hancock, 1960, fig. 6, p. 316; 2000, p. 24) which suggests the calculated distance at the coastal outcrop is plausible.

This revised thickness is more sensible than the 2.5 m required if the main Catton Sponge Bed had been taken to crop out on the foreshore at the “new” Lifeboat Station. With the top of the Weybourne Chalk Member moved to the vicinity of 2.0F on the foreshore at low tide mark, all of the chalk from that point west, at least as far as the westernmost edge of Robin Friend (NGR TG 143 436; Fig. 3), must be included within the Weybourne-3 Chalk.

The base of the Weybourne Chalk is taken to be at flint band ‘X’ in the cliff between Weybourne and Sheringham, (Wood, 1988, p.33; but note an important typographic error [underlined here], “...flint Z of the coastal stratotype (rather than flint Z as in the original definition...” this is correctly referred to as ‘X’ on page 34). Flint band ‘X’ enters into the top of the cliff about 100 m east of Weybourne Hope where the chalk cliff is almost at its highest, at least 6 m above low tide mark. Using the dip correction, flint band ‘X’ should reach the low tide mark approximately 1 km east of here, in the vicinity of Old Butt’s Gap (NGR TG 1275 4370). However, exposure has

not recently been good enough to prove this by finding the distinctive hardground fauna associated with flint band 'X'. Nevertheless, a thickness for the Weybourne Chalk can be calculated using the distance at low tide between the projected base of the Weybourne Chalk and the base of the succeeding Beeston Chalk on the beach. On this basis the Weybourne Chalk is 23 m thick, essentially the figure given by Peake & Hancock (1961, 1970).

For the Beeston Chalk, the absence of a defensible value for the dip at the coast (there are no vertical sections where this can be measured), or of a verified series of overlapping inland exposures, means that the current thickness estimate of 23 m (Johansson & Surlyk, 1990) must be regarded as provisional.

### **INLAND SECTIONS**

Most of the published inland sections that include the base of the Beeston Chalk have been correlated using one or more of the CSB hardgrounds. There is not usually anything characteristic about a single hardground that permits unequivocal identification. Other lithological features and/or specific fauna are thus critical to allow concrete identifications. Thus, although detailed logs are available for substantial temporary sections exhibiting hardgrounds (e.g. the foundations for the Norwich Union building between Westlegate and St. Stephen's Street, Norwich at NGR TG~229 081) that surely belonged to the Catton Sponge Beds, they cannot be placed in the CSB series as the stratigraphically critical macro- and meso-fossils are usually too scarce.

### **LOCALITIES**

#### **Castle Mall, central Norwich (NGR TG 232 085)**

Excavation during 1987-1991 of the extensive site that became the Castle Mall shopping centre in Norwich is the only recent inland temporary section in which all four of the Catton Sponge Beds could be seen together unequivocally. CSB 1 and 4 were impersistent when traced laterally whilst CSB 2 and 3 remained strong (Peake & Hancock, 2000, p. 24). Mr. Norman Peake has also stated that he confirmed the presence of all four of these hardgrounds at Sheringham, but precise data on where they crop out is not available.

In an undated, unpublished private letter to an unknown recipient Mr. Peake was clearly aware, having seen the Castle Mall section, of the probable correlation between sections at Catton Grove, Halfway House, and Stoke Holy Cross published in Wood (1988). The letter also reveals some confusion or contradictions about where he thought

the various Catton Sponge Beds cropped out on the coast: he was clearly debating how best to deal with the Catton Sponge Beds stratigraphically, including the issue of where to place the junction between the Weybourne and Beeston Chalks.

#### **Caistor St. Edmund chalk pit (NGR TG 2390 0466)**

The Caistor St. Edmund chalk pit section (shown as part of Fig. 6) has not previously been integrated into the succession. In 1970 the base of Caistor St. Edmund chalk pit [NGR TG 2390 0466] was above the top of the CSBs (as understood then). However, it is proposed here that the ‘Baculites Bed’ of Wood (1988) is the expression of CSB 1. Identification of CSB 1 allows correlation with the same hardground at the top of the former section at Stoke Holy Cross (see below and Fig. 4). As Stoke Holy Cross has already been correlated using CSB hardgrounds 2 and 3 to the stratotype at Catton Grove (Wood 1988; Fig. 4), a composite vertical section can be constructed for the total thickness from the base of the Beeston Chalk to the top of Caistor St. Edmund chalk pit. A thickness of 18 – 20 m is calculated, depending on which locality is used for the thickness of CSB hardground 1, and whether the figure for the height of the section at Caistor St. Edmund chalk pit is taken from the text (16.81 m) or figure 8 (15.7 m) of Wood (1988). Wood (pers. comm. June 2006) has confirmed that the ‘text’ value of 16.31 m is correct.

In 2003–4 three previously unrecognised major omission surfaces (“MOS’s”) were identified in the top 3 m of the Caistor St. Edmund chalk pit section. The upper pair is associated with sparsely distributed “nests” of crushed, worn and broken *Echinocorys*, the lowest is sparser still. These so-called “nests” of *Echinocorys* are current-garnered tests that have been swept, crushed (to varying degrees) and broken into scour hollows created during an earlier phase of turbulent current flow. The crushed tests provided a valuable micro-habitat (spatial refuge) for a range of gastropods, bivalves and encrusting bryozoans. Examination of the meso-fauna, in particular the bryozoa, reveals that the taxa are similar to the “nests” in the Lower, Middle and Upper Old Butts MOS’s (Whittlesea 2006) near the top of the Beeston Chalk Member on the north Norfolk coast (F12, Fig. 3). However, it is also clear that the section at Caistor St. Edmund does not extend up to the top of the Member, there being no evidence of the Water Lane MOS (see above) or its specialised fauna.

Near the top of the Caistor St. Edmund section between beds ‘B’ and ‘b1’ (Fig. 6), a 0.8 m thick bed of hard white chalk is present: it is rich in yellow phosphatised horizons, burrows, fossil moulds, belemnites and brachiopods, mainly *Carneithyris*,

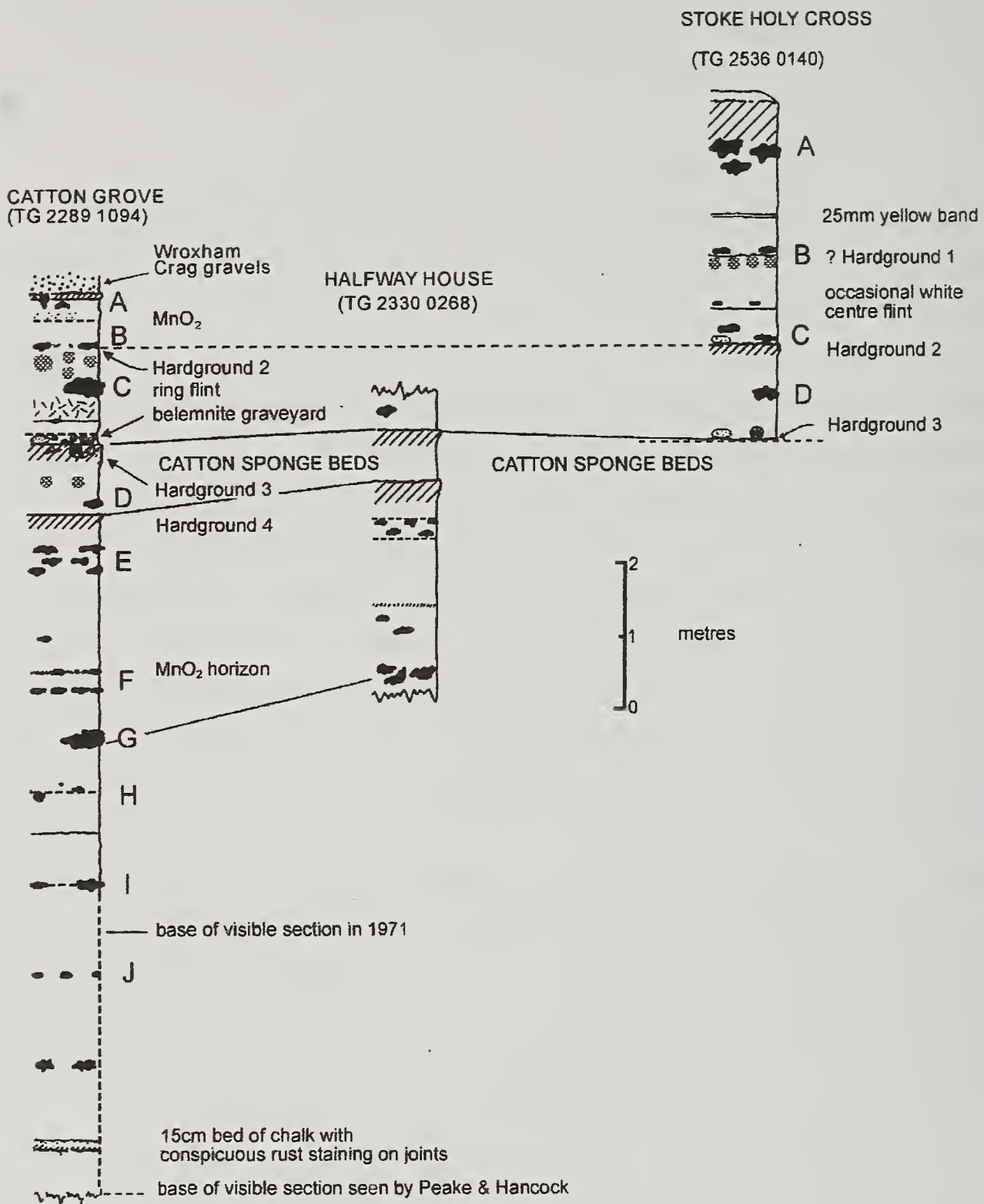
*Neoliothyridina*, *Cretirhynchia*, *Magas* and *Kingena*. This should crop out on the coast (in the vicinity of the Old Butts MOS's) and be easily recognisable if it retains its character along the strike. It has not been recognised to date.

#### **Stoke Holy Cross (NGR TG 2356 0140)**

(NB: In nearly all previous publications this site's grid reference has been incorrectly given as TG 2536 0140, the second and third digits of the easting having been transposed.)

Stoke Holy Cross was an important section in a disused chalk pit (now overgrown). A narrow chalk face, 3.3 m tall, excavated in a trench, included CSB 2 and 3 (Fig. 4), allowing correlation with Catton Grove by Wood (1988). At that time, no overlap with Caistor St. Edmund chalk pit had been demonstrated. However, the proposal that Wood's "Baculites Bed" at Caistor St. Edmund represents CSB 1 (see above) and this author's recent discovery of the stratigraphically important heteromorph ammonite *Neancylocerus bipunctatum* (Schlüter) from the top metre of Stoke Holy Cross (now in the author's collection in Norwich Castle Museum) strongly supports the long suspected stratigraphic overlap of these two sites. Discovery of *N. bipunctatum* is important because Mortimore, *et al.* (2001, p. 354) noted that in the Goff collection in Norwich Castle Museum there were specimens of this ammonite that had been collected from the extreme base of Caistor St. Edmund pit. Wood (1988, p. 69) and Mortimore *et al.* (2001, p. 354) speculated that these might have come from an even deeper level in a trial hole. However, Dr. Goff (November 2005) in correspondence with the author has clarified that the specimens came from levels accessible in the base of the pit when it was at its deepest (almost certainly Wood's "Baculites Bed") and not from a trial hole.

The CSB 1 at Stoke Holy Cross is interpreted here to be the band of weakly indurated chalk (noted by Wood, 1988, pp. 66-67) correlating with the Baculites Bed at Caistor St. Edmund. This relationship has been suggested to Mr. Wood who noted that if correct, his strong flint band 'A' (labelled 10, fig. 7, p. 114, Wood 1988) at Stoke Holy Cross (see also Fig. 4) would have no counterpart at Caistor St. Edmund. However, this can be solved if Wood's flint band 'A' correlates with the strong flint band 'O' (labelled 1, in fig. 8, p. 115, Wood 1988) at Caistor St. Edmund (see also Fig. 6). Similarly, flint band 'B' at Stoke Holy Cross (Fig. 4) could correlate with 'P' at Caistor St. Edmund (Fig. 6). Although with this correlation the spacing of these flint bands at Stoke Holy Cross is wider than at Caistor St. Edmund, this is consistent with the presence of the



**Fig. 4.** Correlation of sections in the Upper Chalk at Catton Grove, Halfway House and Stoke Holy Cross, indicating inferred correlations. The diagram is based on Wood, 1988, fig. 7) but updated with new information from the present author. The likely position of CSB hardground 1 is also marked and thought to correlate with the *Baculites* Bed at Caistor St. Edmund; similarly flint band A at Stoke Holy Cross is here proposed to correlate with band O at Caistor St. Edmund (Fig. 6). NB. Flint band lettering for Catton Grove is not the same as that used by Peake and Hancock (1961, 1970).

well-developed hardground (“Baculites Bed”) at Caistor St Edmund, resulting in a more condensed section.

The difference in size of the exposed sections at Stoke Holy Cross and Caistor St. Edmund is also significant. The Stoke Holy Cross excavation was no more than a couple of metres wide and narrowed rapidly with depth, whereas Caistor St. Edmund was, and remains, a large working quarry. A section drawn at the former would be a ‘narrow window’ of all that could be seen, whereas at the latter it is a précis of details seen along ~100 m width of section. This is important when comparing the nature and content of a single bed seen at different localities: e.g. flint band ‘C’ at Catton Grove (labelled 7 in fig. 7, p. 114, Wood, 1988) consists of massive isolated flints, twice the size of those in flint band ‘D’ at Stoke Holy Cross (also labelled 7 in fig. 7, p. 114, Wood, 1988) with which they are correlated. This and other differences between Stoke Holy Cross and those sites it was correlated with were known and remarked upon by Wood (1988).

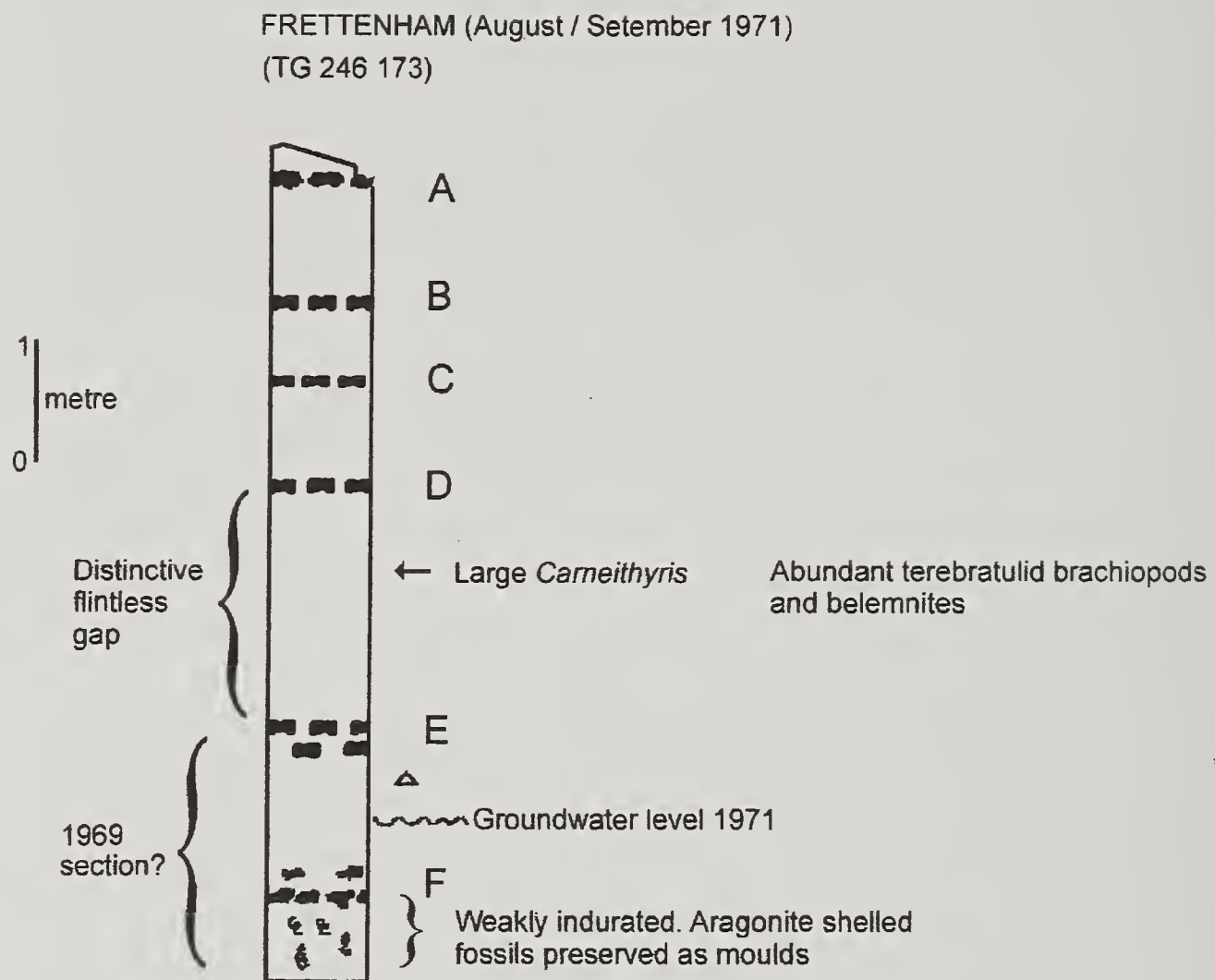
#### **St. James’ Hollow chalk pit, SSSI, Heathgate, Norwich (NGR TG 242 094)**

This huge former chalk pit is now a children’s playground. It exhibits two small exposures immediately below the chalk surface. Excavation of a ~2.5 m high section by the author in the late 1970s yielded a diverse fauna (145 species) although most were single specimens. Overall, the fauna and facies recorded from the top 2.5 m are very similar to that between bands ‘B’ and ‘C’ at Caistor St. Edmund.

At this locality Peake & Hancock (1961, p. 318) recorded “... *Magas pumilus* J. Sowerby and abundant “*Isocrinus*” ossicles.” If the “abundant “*Isocrinus*” ossicles” belonged to *Austinocrinus*, and had been collected from a lower bed than that reached by the author, this would allow tentative correlation with Wood’s *Austinocrinus* Bed at Caistor St Edmund. Peake & Hancock (1961) placed this pit under their discussion of the Paramoudra Chalk. However, subsequent discussions between the author and Mr. Peake led to a reassessment: we concluded that its upper beds come just below the junction of the Beeston and Paramoudra Chalks.

#### **Frettenham Chalk Pit (NGR TG-246 173)**

Mr. Wood (pers. comm. 2004) kindly made available to the author an unpublished log of the former pit at Frettenham that exposed 7.3 m of chalk including six flint bands (Fig. 5). Peake & Hancock (1970, p. 339F) were of the opinion that the Frettenham sequence is located “around the base of the Paramoudra Chalk”. At Frettenham, Wood found no evidence of the ‘hardgrounds’ that occur in the upper 3 – 4 m of the Beeston Chalk on



**Fig. 5.** Graphic log of Frettenham chalk pit, as logged by Mr C. Wood in 1971. The pit is now in-filled. The gap between flint bands D and E is comparable (and correlated here) with the largely flintless 3 m interval between bands B and D at Caistor St. Edmund (Fig. 6). Note that the relationship between the deep 1969 section and the 1971 section is uncertain as they were not seen in the same part of the quarry.

the coast. Neither did he see any of the distinctive fauna known to him at the top of the Caistor St. Edmund section. Indeed, neither Wood, nor Peake and Hancock thought there was any substantial overlap between the Frettenham and Caistor St. Edmund sequences.

However, Christensen (1995) in a major revision of the genus *Belemnitella* in Norfolk observed that *Belemnitella minor* I subsp. occurred at Frettenham, but not *B. minor* II subsp. *B. minor* I subsp. is the zonal fossil for the Beeston Chalk and *B. minor* II subsp. is that for the succeeding Paramoudra Chalk. Furthermore, both Caistor St. Edmund and Frettenham are unique in sharing 5 *Belemnitella* species, a situation unrivalled elsewhere. On this evidence the present author thinks it would be very surprising if there were no overlap between the two sites.

## CORRELATIONS

### Inland

Wood (1988) has demonstrated a correlation between Catton Grove and Stoke Holy Cross using two of the Catton Sponge Beds (Fig. 4). The presence of the heteromorph ammonite *Neancylocerus bipunctatum* (Schlüter) is now known from the extreme base of Caistor St. Edmund (Mortimore *et al.* 2001) and from the top metre of Stoke Holy Cross. This provides a palaeontological link between these sites: hardground 1 of the CSBs.

The belemnite palaeontology discussed above suggests that Frettenham Pit was excavated in Beeston Chalk. Wood's log for Frettenham (reproduced here as Fig. 5) shows a 2 m flintless interval between bands 'D' and 'E'. Wood's section is composite in that the section from A to D and E downwards were seen in different parts of the quarry at different times. The gap, though, is comparable with the 3 m interval between bands 'B' and 'D' at Caistor St. Edmund (Fig. 6; flint band 'C' at Caistor St. Edmund is 2 m below band 'B', but is very sparse.) At both locations the flint band marking the base of the flintless interval is underlain by a horizon where an *Echinocorys* Bed is developed, in turn underlain by a hardground. Both horizons are similarly spaced but developed to differing degrees.

Wood (1988) did not log the three *Echinocorys* horizons now known to exist at the top of Caistor St. Edmund; the higher pair consists of well-spaced "nests" of variably crushed and broken tests and it would be easy to examine a length of section that did not exhibit one. If they were present at Frettenham they were either overlooked or not visible. Incorporating an overlap between Frettenham and Caistor St. Edmund would leave approximately 2 m of chalk and two flint bands that would take the top of Frettenham very close or into the "Bone Bed" horizon seen at the coast.

Since Mr. Wood published his log of Caistor St. Edmund another flint band has been exposed at the top of the quarry in the far south western corner. It is 0.9 m above the flint band labelled '15' in Wood (1988, fig. 8) and tails off into the chalk surface when traced east, rapidly becoming part of the flint lag. It is shown in the revised log for Caistor St. Edmund here (Fig. 6) as band 'Z' and is of similar character to 'A'. Its presence reinforces the overlap between the logs for Caistor St. Edmund and Frettenham.

The inland Beeston Chalk thickness is thus calculated as:

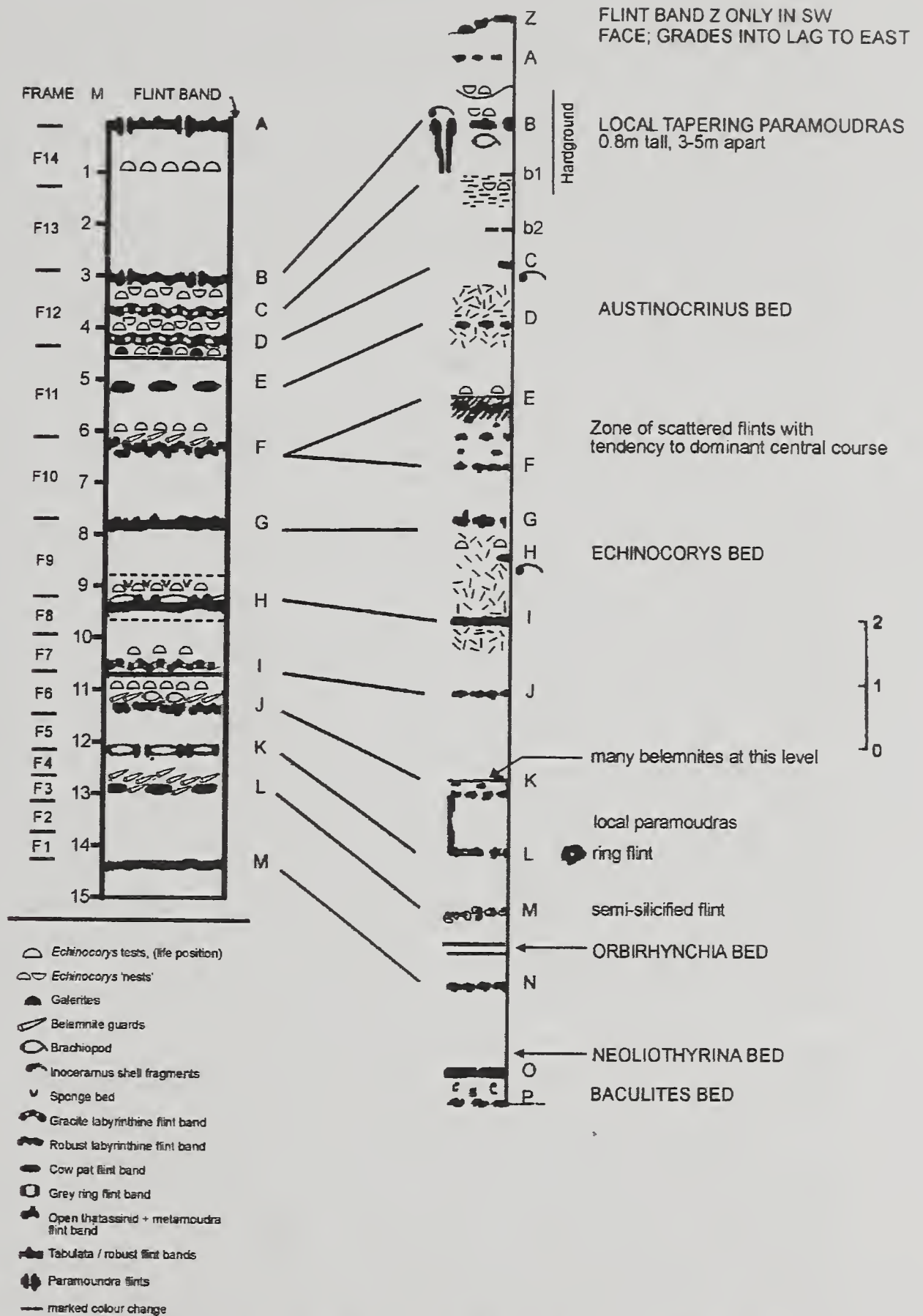
Frettenham [allowing 3.9 – 4.5 m overlap with top of Caistor St. Edmund]	2.00 m
Caistor St. Edmund	16.31 m
Stoke Holy Cross [allowing 1 m overlap of top with base of Caistor]	3.50 m
<b>Total</b>	<b>21.81 m</b>

#### **North Norfolk Coast-Inland**

The proposed correlation between Caistor St Edmund and Frettenham makes it unnecessary to incorporate up to 10 – 11 m of chalk and at least 6 – 10 flint bands at Frettenham into a position at the top of the Member. There are insufficient flint bands on the coast with which to make any additional matches. Moreover, if this correlation is correct, it implies there is 18 m of chalk from CSB 2 at 1.0F to F15.0 on the coast; that equates to a dip of 6.4 m/km. There is an additional 1 m of chalk above F15.0 to the top of the Beeston Chalk (equivalent to an outcrop 31 m wide on the beach) and probably a similar figure representing the imprecision with which the westernmost boundary of CSB 3 would crop out on the foreshore. If the figure of 6.4 m/km is applicable to the full breadth of the strike (3.2 km) this implies a thickness for the Member of 20 - 21 m at the coast. If the increase in the dip from south to north noted earlier by Boswell continues, this would contribute to a modest further increase in thickness.

The correlation proposed in Figure 6 concentrates mainly on relations between Caistor St. Edmund and that part of the coast logged by Whittlesea (2006): horizons corresponding to the Stoke Holy Cross section are not currently visible on the coast, and the author did not log Frettenham when it was exposed. The number of flint bands, hardgrounds, major omission surfaces (MOS's), abundant belemnite horizons (ABHs) and sparse/abundant echinoid horizons (SEHs/AEHs) present at the coast and at Caistor St Edmund appear in broadly the same sequence and are similarly spaced. The observed facies variations may well correspond to transgressive – regressive cycles,

# Correlating the Beeston Chalk, Norfolk



**Fig. 6.** Proposed correlation of the coastal section between Sheringham and West Runton (Whittlesea 2006) and that at Caistor St. Edmund chalk pit (emended from Wood 1988). Hatched area in the Caistor St Edmund log between flint bands C - D and G - I are rich in *Inoceramus* fragments. NB. Flint band lettering for Caistor St. Edmund is not the same as that used by Peake and Hancock (1961, 1970).

which may themselves reflect Milankovich orbital periodicity (Godwin 1987). In the Beeston Chalk at Caistor, (Godwin 1987) recognised three 'Milankovitch macro cycles'. While it is tempting to use such lithofacies cyclicity to aid correlation, it is important to be aware of the potential complications.

The significant lowering of sea level associated with major eustatic regression tends to increase the area over which non-deposition occurs, allowing formation of nodular chalks and hardgrounds (Kennedy & Garrison, 1985). These conditions occur longest in shallower water, which is generally in the more onshore regions. Sedimentation resumes during any succeeding transgression.

In the context of the Norfolk Chalk it is generally accepted that south and central Norfolk was closer to the London – Brabant Massif and therefore in shallower water (Transitional Province – see e.g. Mortimore *et al.*, 2001) relative to the deeper water of the north Norfolk coastal area (Northern Province – see e.g. Mortimore *et al.*, 2001). A major regression with occasional minor transgressive phases would produce a single hardground in shallow onshore waters. In deeper water a hardground would be present initially, while the transgressive phases might temporarily terminate hardground conditions allowing sedimentation to recommence. The result will be that onshore hardground formation (Caistor St. Edmund) would be more or less continuous; whereas offshore that same time interval would be represented by a later formed hardground followed by a series of major omission surfaces separated by sediment deposited during the minor transgressive phases. This could explain why the three Old Butts MOS's in between F11.9 and F12.9 on the coast have no expression inland; more specifically, they probably correlate with the single major hardground at the top of Caistor St. Edmund chalk pit between flint bands 'B' and 'C' (Fig. 6) and the sparse *Echinocorys* nests.

Similarly, the well known *Inoceramus* 'flood' horizons (Fig. 6) at Caistor St. Edmund (Godwin 1987; Wood 1988) have not so far been seen in the relevant part of the north Norfolk coast sequence. This is almost certainly because of facies variation. In shallower waters (Caistor St. Edmund) strong currents winnowed fines from amongst *Inoceramus* shell fragments, helping create the 'floods'. This process was less marked or absent in the in deeper-water settings (north Norfolk).

### Correlation Problems

The fauna, in particular some of the benthos, recovered from Frettenham and the coast does not match that from the top of Caistor St. Edmund chalk pit (Wood 2003, pers. comm.). Stoke Holy Cross and Halfway House are both in the northernmost part of the

Transitional Province. Caistor St. Edmund is located precisely on the boundary of the Transitional and Northern Provinces; all other sites mentioned are in the Northern Province.

No log is so far available for the western section of coast between the Two Lifeboats Hotel and the new Sheringham Lifeboat Station, as this is almost invariably covered by modern beach sand. However, this is less crucial now as it seems likely that most of the chalk on the foreshore to the west of 2.0F belongs to the underlying Weybourne-3 Chalk. Consequently, no attempt is made here to refine the correlation for that part of the coast.

Where data could not be logged to the east between the Two Lifeboats Hotel and The Driftway (due to beach sand cover in F1 and F2), the separation of these locations was used to calculate the thickness of unseen chalk ( $270 \text{ m} \times 5 \text{ m/km} = 1.3 \text{ m}$ ) also shown at the base of the SVS of Whittlesea (2006, fig. 3). This gap might reasonably be expected to accommodate an extra flint band, since flint band spacing averages 1 per 0.98 m, (based on Caistor St. Edmund chalk pit being 15.7 m deep). Moreover, with a revised dip of 6.4 m/km, 270 m would represent a thickness of 1.7 m and could accommodate two flint bands and CSB 1.

Although the published location of CSB 2 on the coast is “in front of” the Two Lifeboats Hotel (Peake & Hancock, 1970) it has not been verified in this study. If the precise location and horizon (CSB 2) is subsequently confirmed then CSB 1 should crop out approximately 64 m to the east of it. Moreover, if CSB 1 were as weakly developed on the coast as it is at Stoke Holy Cross then it would be easy to overlook, although Peake (pers. comm.) claims to have recognised it.

In mapping the north Norfolk coast it is not possible to identify flint bands recognised inland consisting of scattered, isolated individuals, as winter seas quickly remove these. If the sparse flint bands ‘C’, ‘H’ and ‘M’ at Caistor St. Edmund retained their character at the coast, and as a consequence were removed by wave action, there should be three correspondingly extensive stretches of foreshore lacking any flint bands. Using the figures for the dip of Boswell (1920) and Whittlesea (2006 for the intervals between flint bands ‘B’ and ‘D’ (3.2 m), ‘G’ and ‘I’ (1.7 m) and ‘L’ and ‘N’ (2.1 m) there should be flint free stretches of foreshore of the following widths:

$$\text{B} - \text{D}: 3.2/6.6 \text{ m/km} = 480 \text{ m or } \text{B} - \text{D}: 3.2/5 \text{ m/km} = 640 \text{ m}$$

$$\text{G} - \text{I}: 1.7/6.6 \text{ m/km} = 257 \text{ m or } \text{G} - \text{I}: 1.7/5 \text{ m/km} = 340 \text{ m}$$

$$\text{L} - \text{N}: 2.1/6.6 \text{ m/km} = 318 \text{ m or } \text{L} - \text{N}: 2.1/5 \text{ m/km} = 420 \text{ m}$$

Nowhere is there a stretch of foreshore as much as 200 m wide that is bereft of a flint band. The conclusion that at least the first two flint bands had changed their character is unavoidable and the same must be true to a degree of the benthic fauna. Mr. Peake (pers. comm.) had always argued that “the chalk on the coast is flintier than inland”, by this he meant the flint bands were more substantial rather than more numerous.

Across F13 the chalk is anomalous in lacking clearly defined flint bands (Whittlesea 2006, 2007): these should crop out (irrespective of the dip value chosen) over a stretch of beach no more than 50 – 100 m wide. An exceptional low tide in September 2006 showed that the whole of the top 0.5 m of the chalk surface here is intensely indurated (post-Cretaceous diagenesis) such that it erodes at almost the same rate as the flint bands it contains (Whittlesea 2007). This explains the failure to discern discrete flint bands in F13.

#### **ACKNOWLEDGEMENTS**

The author is deeply grateful to Mr. C. J. Wood for permission to utilise some of his unpublished logs and for much constructive input to an earlier version of this paper and to Dr. J. Goff for supplying information on the provenance of material from Caistor St. Edmund collected by him and his colleagues. The author is also deeply grateful to Mr. N. B. Peake for innumerable lengthy discussions over many years on the Upper Campanian and Lower Maastrichtian of Norfolk and elsewhere.

#### **EDITOR’S NOTE**

This article was in the final stages of revision for publication at the time of the author’s death. The editor has made some small final changes to the text and figures, but it is hoped, has not changed the meaning intended by the author. The editor takes full responsibility for any errors introduced after the author’s death.

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### GLOSSARY

ABH	Abundant belemnite horizon.
AEH	Abundant echinoid horizon; the echinoid is usually <i>Echinocorys</i> but may include significant but subordinate <i>Galerites</i> .
F	Abbreviation for “Frame” – see Whittlesea (2006) for details. A numbered space between a precisely located and defined pair of groynes on the foreshore on part of the north Norfolk coast.
MOS	Major omission surface.
RNLI	The Royal National Lifeboat Institution.
SEN	A sparse <i>Echinocorys</i> “nest” i.e. current garnered tests that have been gathered into a small local scour hollow. The individual nests may be well spaced out across an omission surface, but typically contain 5 – 10 tests. The tests may have experienced varying degrees of damage and have variable amounts of epifauna.
SVS	Synthetic vertical section; an actual horizontal section can be converted into a SVS using simple trigonometry and a value for the dip.

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# **FURTHER OBSERVATIONS ON THE BEESTON CHALK IN THE VICINITY OF WATER LANE, WEST RUNTON**

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## **ABSTRACT**

*September 9<sup>th</sup> 2006 saw the highest tide on the north Norfolk coast for more than 20 years. Associated with this was a corresponding exceptionally low tide that enabled the chalk immediately to the west of Water Lane, West Runton to be examined in far greater detail than hitherto possible. It was established that the apparent absence of any chalk in between flint bands was not due to a structural anomaly but to the extreme hardness of the chalk.*

## **INTRODUCTION**

In 2006 Whittlesea described the outcrop of the Beeston chalk between Sheringham and West Runton (Whittlesea 2006). The codes used by Whittlesea consisted of a site code ('SGH' for Sheringham) and a sub-site code corresponding to a numbered interval between a pair of groynes that was referred to as a 'Frame' (abbreviated to 'F'; see Whittlesea (2006), fig. 2, pp. 8-9 for map with codes for sites; updated in Whittlesea (2007, this volume) as fig. 3, p. 14-15). The 'Frames' were numbered from west to east starting at 'F1' and continuing to 'F14', which crops out in front of the slipway at Water Lane, West Runton. SGH(F13) then, is the inter-groyne space immediately to the west of Water Lane and is some 300 m wide.

Whittlesea (2006) remarked that the chalk in F13 was unusual in that with a Frame breadth of 300 m and an estimated dip of 5 m/km, two flint bands separated by a stretch of beach exposing chalk should be visible, the average vertical separation of flint bands in the Beeston Chalk being ~0.9 m. Instead, there appeared to be simply a single continuous flint band present. It was proposed that this might be due to a fault and it was noted that the chalk in F13 was noticeably higher than that in F14.

### **GENERAL OBSERVATIONS**

The beach between Weybourne and Cromer is essentially perpendicular to the strike. With a low dip estimated at 5 m/km (Whittlesea 2006; later revised to about 6.4 m/km by Whittlesea 2007) and no known flint band exceeding 0.5 m in thickness (rarely more than half that) the beach should display a series of flint bands separated by chalk beds. The chalk here is generally soft and has often been subject to severe permafrost damage; such chalk is eroded to present an essentially smooth, planed surface. Even where the chalk is extremely hard, such as at the hardground in F6 beneath Beeston Hill, it is still eroded between the gently inclined chalk beds so that it presents a deeply channelled surface where these channels parallel the strike.

### **OBSERVATIONS ON F13**

During the exceptional low tide on the 9<sup>th</sup> September 2006 it was possible to observe much more of the chalk and flints on the lower foreshore than normal. It is now clear that the chalk here is exceptionally hard, probably due to diagenetic cementation. As a result marine erosion progresses at roughly the same rate in both the hardened chalk and the flint bands it contains. The surface of the chalk stands above the general surface of the beach – rather like a mini ‘mesa’ landform, and the chalk is not eroded between the chalk beds that cross F13. Instead, seaweeds – which everywhere else only gain a temporary hold before the chalk to which they are attached is undercut and dislodged – may gain a hold in a crevice in the chalk. These are then swirled around by the incoming and outgoing tides until their holdfast is in the bottom of a crater-like depression. Similarly, limpets (*Patella vulgata* Linnaeus) create large, deep attachment scars on the lower shore and clearly remain in place for a substantially greater length of time than elsewhere along this part of the coast. The whole beach is a sub-level area covered by pools and depressions that have no particular relationship to the dip and strike of the chalk itself. This explains why this area is popular with modern intertidal species that like hard rocky surfaces; it does not however, explain why or how it became so hard. In spite of the greater area of inter-tidal beach visible, the persistent presence of a dense covering of sea weeds, chiefly bladder wrack (*Fucus vesiculosus*) and toothed wrack (*Fucus serratus*), makes examining the geology extremely difficult.

It can be seen, however, that the basal Stone Bed of the overlying Wroxham Crag immediately overlies the chalk surface in both F13 and F14 and that the surface level is different in each. Hence the process responsible for the hardening of the chalk in F13 (it

is intensely cryoturbated at the top of the beach in F14) must have occurred before deposition of the Stone Bed.

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Copies of the Bulletin (including older back copies) can be obtained from the editor at the address on p.1; it is issued free to members.

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The figure on the front cover is part of figure 3 from the main paper by Whittlesea in this issue of the Bulletin, showing the inferred positions of the Catton Sponge Beds (CSB) in the Beeston Chalk at Sheringham on the Norfolk coast.